COMPLETION REPORT

Project No. A-049-MONT

GROUND WATER SEEPAGE AND ITS EFFECTS ON SALINE SOILS

MUJWRRC Report No. 66

Montana University Joint

Water Resources Research Center

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by

Loren L. Bahls
Montana Environmental Quality Council
Helena, Montana 59601

and

Marvin R. Miller
Montana College of Mineral Science
and Technology
Butte, Montana 59701

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SALINE SEEP IN MONTANA

by
Loren L. Bahls
Ecologist*
and
Marvin R. Miller
Hydrogeologist**

INTRODUCTION

Saline seeps are recently developed saline soils in nonirrigaged areas that are wet some or all of the time, often with white salt crusts, and where crop or grass production is reduced or eliminated.*** They are manifestations of 20th century dryland agriculture and the crop-fallow rotation system necessary for moisture conservation and small grain production on the scale practiced in Montana. The widespread occurrence and rapid growth of saline seeps have been recognized as one of the most serious conservation problems in the northern Great Plains (14).

A 1971 Soil Conservation Service (SCS) survey revealed that more than 80,000 acres of nonirrigated Montana cropland had been lost to saline seeps (6). Serious outbreaks of seep have now appeared in northcentral and northeastern Montana and are increasing at a rate of over 10 percent a year. Other estimates show that 150,000 to 250,000 acres of cropland have been lost, and if the acreage of saline farm, recreation, and stockponds as well as badly eroded

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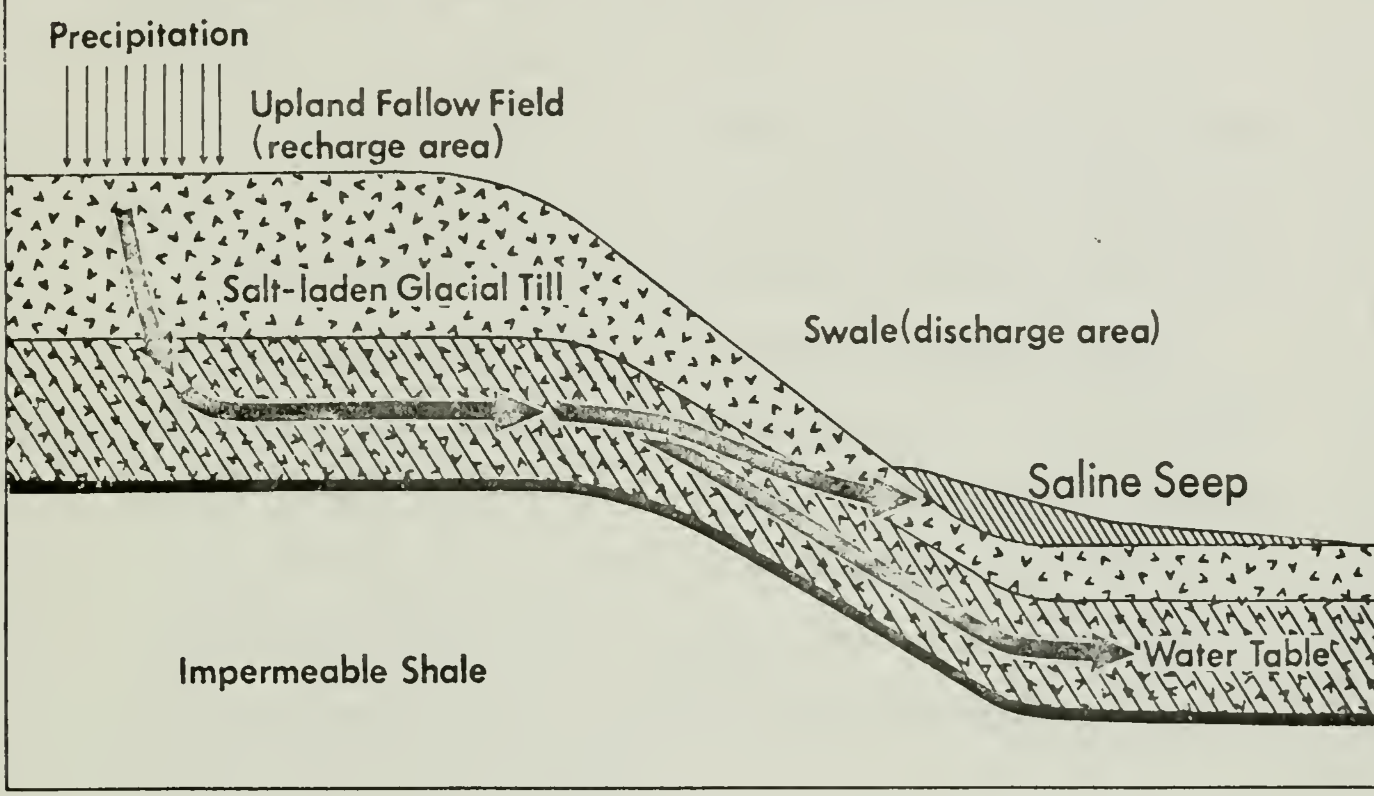
*Ecologist, Montana Environmental Quality Council, Helena
**Hydrogeologist, Montana Bureau of Mines & Geology, Butte
***Definition accepted by Governor's Committee on Saline Seep, August 30, 1973.

coulees and "seeped" drainageways were included, the affected area would be much greater. Saline seep is known to be highly destructive to Montana's soil, water, and wildlife resources, but the true extent of its adverse environmental effects is only guesswork.

Although aggravated by the crop-fallow system now in use, the saline seep problem stems from the geology of the northern Great Plains region. The surface material is glacial till up to 70 feet thick. The till is underlain by a thick marine shale formation that is impermeable to water. Both the till and the shale contain an abundant supply of natural soluble salts. Excess water, evidently produced by dryland moisture conservation, moves through the till, picks up salts, and builds up on top of the shale, froming a "perched" water table. This excess water gradually moves downslope, accumulates in the lower swales, and eventually reaches the surface and evaporates, leaving the dissolved salts behind (Figure 1).

This paper outlines the history of the development of saline seep in Montana and efforts to control it; it describes in detail the hydrogeological setting of the area affected and notes the potential for spreading throughout much of the northern Great Plains. The latter portion of the paper deals with environmental aspects and implications of saline seep, including environmental impact and possible control technologies.

Fig. 1 Saline Seep Formation



HISTORY

Patches of alkali dotted the northern plains before the white settlers arrived. Lewis and Clark referred to them in their journals: "The salts which have been mentioned as common on the Missouri are here so abundant that in many places the ground appears perfectly white, and from this circumstance the river may have derived its name (8)." These spots persist today, mostly on rangeland, but are apparently nothing more than static, residual salt accumulations from some natural evaporative process working over geologic time. Unlike

present-day seeps, these naturally occuring salt deposits do not spread. For these reasons they are not included in the definition of saline seep given at the beginning of this paper.

The saline seep story began between 1910 and 1920 when most of the native grassland of northern Montana was plowed. Undoubtedly some excess water accumulated beneath the root zone for many years following, but extended periods of drought and inefficient farming practices probably slowed saline seep development. The phenomenon (locally called alkali or north slope alkali) first appeared in Montana in the late 1940s, just a few years after the alternate crop-fallow farming system became well established; after large, high-powered farming equipment became available; and after the beginning of widespread chemical weed control (7).

Some early accounts show sporadic concern about the problem. In 1947 the Montana Cooperative Extension Service (MCES) made a brief field investigation and wrote an evaluation (26). In 1954 an article titled "North Slope Alkali" appeared in the Montana Farmer Stockman (29). And, in 1955, primarily through the efforts of R. W. Warden, first district conservationist for the SCS at Fort Benton, a team of SCS specialists investigated seep areas and prepared a short report.

The Highwood Bench south of Fort Benton was one of the first areas in Montana to be affected. Salt accumulation there has become increasingly serious, with 10,000 to 12,000 acres of nonirrigated farmland put out of production during the past eight years. It was not until 1968-69, however, that an organized plan of action was initiated by several farmers on the bench. The Highwood Alkali Control Association (HACA) was formed in 1969 with 75 members. At the association's behest, the Montana Bureau of Mines and Geology (MBMG), Montana State University (MSU), Agricultural Research Service (ARS), and SCS have begun to investigate the problem.

To quantify the rates of growth and areal extent of saline seeps on the bench, aerial photographs of the Nine Mile watershed taken over a 30-year period were used. Accumulated percentages of the total land area in the watershed (19.1 square miles) affected by saline seeps are as follows:

1941	0.1 percent
1951	0.4 percent
1956	2.2 percent
1966	9.1 percent
1971	19.4 percent

Of the 19.4 percent, about 15 percent is cultivated dryland, much of it poorly drained recharge areas that occupy about 5.8 percent of the watershed. If the present alternate crop-fallow farming system is continued at least 30 to 40 percent of the watershed will probably be affected by saline seep. This compares to less than 0.1 percent of the watershed affected by saline conditions under the native sod system.

Progress since 1969 has been modest at best, but some awareness has been achieved. In February 1971 the HACA sponsored the Saline Seep-Fallow Workshop, where data was presented showing saline seep to be regional in scope and a much more serious environmental problem than previously thought. While MBMG, MSU, and SCS research continued, additional research was initiated by the ARS at Sidney, Montana, and Mott, North Dakota, and by the Candian Department of Agriculture at Lethbridge, Alberta; the HACA made extensive efforts to secure additional research funds; the 1973 Montana legislature passed a joint resolution (23) asking the governor to marshal all state resources and seek emergency aid from the federal government to halt saline seep; the governor appointed an emergency saline seep committee to develop a plan for correcting the problem; and that committee, with the Environmental Quality Council (EQC), requested technical assistance from the Environmental Protection

Agency (EPA) relating to water quality problems arising from saline seep.

HYDROGEOLOGICAL SETTING

Much of the definitive hydrogeological work relative to saline seep has been conducted on the Highwood Bench near Fort Benton. The details of geological history and mode of seep formation vary from area to area, but the situation on the bench may serve as a general model for the entire northern Great Plains region.

The geological history of northern Montana and the bench included long periods of sedimentation, emplacement of volcanic and plutonic igneous rocks, regional uplift, erosion, and glaciation. Throughout most of the Paleozoic and the Mesozoic (600 to 70 million years ago), thousands of feet of predominatly marine sediments were deposited in this region. At the end of the Mesozoic (late Cretaceous) and extending into the early Tertiary (70 to 50 million years ago), the entire area was uplifted, faulted, and folded, producing the Rocky Mountains to the west and south, gently tilting the sedimentary rocks to the northeast, and subjecting the area to erosion. The emplacement of volcanic and plutonic rocks that form the Highwood and Bearpaw Mountains also occurred during this time. Continued erosion during the Tertiary stripped away the uppermost Cretaceous sediments and exposed the black shale of the Colorado Group over what is now the

Highwood Bench. This same area was dissected and drained by the ancestral Missouri River, which flowed in a northeasterly direction to Hudson Bay.

During the Pleistocene (one million to 15,000 years ago), glaciers covered the entire region north of the Highwood Mountains two or more times and left a mantle of unconsolidated, poorly sorted deposits (glacial till) that filled most of the pre-existing valleys and produced a gently rolling plain. The ice blocked the drainage of the Missouri River and its tributaries, forcing the streams to change course and cut new channels. During the last 15,000 years, erosion established the present-day drainage pattern in northern Montana.

The glacial till and underlying black shale of the Highwood Bench are geologically important. Drill-hole information and exposures along the Missouri River show till either absent or up to 70 feet thick. Two distinct tills, representing two ice advances, are present--the upper is normally the thicker and is buff to tan, whereas the lower is generally only a few feet thick (absent in some localities) and is light to dark gray. A pebble zone or meltwater layer is often found between the tills. Except for the upper two or three feet--the leach zone of the soil profile--the entire till is loaded with salt crystals.

The till is predominatly unsorted clay and silt with well-rounded pebbles scattered throughout. X-ray analysis of the clay

fraction indicates 80-percent montmorillonite (highly plastic, sodium-rich, expanding clay), 15-percent illite, and five-percent kaolinite or chlorite (2). A few sand and gravel lenses were found in some test holes, but they are normally thin, discontinuous, and small in area. Numerous vertical joints are believed to enhance the vertical movement of water through the till. Infiltration studies on poorly drained upland (recharge) areas indicate downward movement of over five inches of water a day. These high infiltration rates greatly exceed previous estimates.

The black bentonitic marine shale of the Colorado Group that underlies the entire Highwood Bench is 950 to 1,850 feet thick. Owing to erosion and the gentle dip to the northeast, the shale thins to the southwest toward the Little Belt Mountains. A weathered zone, one to eight feet thick at the till-shale contact, is commonly saturated and appears to be the only slightly permeable shale layer. The unweathered shale beneath is completely dry.

Close correspondence between local precipitation and water-table fluctuations means that excess water is moving through the soil to beneath the root zone, through the remainder of the till, and eventually accumulating on the bedrock. Most of this movement occurs in spring, particularly April, May, and the first part of June. The water table may rise a few inches to several feet in years with average or above-

average precipitation. These highs decline during the rest of the year, but usually do not reach the previous year's low, reflecting a continual buildup of excess water. Thus each succeeding wet cycle makes the saline seep problem worse.

In many areas the "perched" water table has built up to a point where coulees that were formerly dry most of the year are now starting to flow year-round. Most of the saline water evaporates before reaching perennial streams, leaving the salts behind to be flushed away during spring runoff, but unless the seeps stop growing, many coulees will soon start to carry highly saline water to all the region's perennial streams.

Saline seeps are a result of local, not regional, flow systems; that is, the excess water that produces the seeps is locally derived. The surface dimension of each wet-saline (discharge) area is directly related to the size of the adjacent upland (recharge) area. Freshwater ponds often cover part or all of the recharge area for weeks at a time, adding large quantities of water to the soil profile and seriously aggravating the seep problem downslope. The importance of recharge areas has for the most part been overlooked. Delineation of these areas, improved drainage where possible, and an intensified cropping system would mitigate the seep problem. Frequently, the recharge area is left fallow while attention is focused on the discharge area--the seep itself.

POTENTIAL REGIONAL PROBLEM

As noted earlier, Montana has already lost over 80,000 acres of cropland to saline seep and the area affected is increasing by over 10 percent a year. Geological conditions that favor saline seep--a variable thickness of glacial till underlain by thick sequences of black marine shale--are similar over vast areas of Montana (12,500 square miles), North and South Dakota (45,500 square miles), and the three prairie provinces of Canada (70,000 square miles). Saline seeps are spreading in that entire region and also in farming areas underlain by the siltstone, sandstone, shale, and coal of the Fort Union formation (21). Here again, excess water is moving downward and accumulating on thin impermeable underclays, in this case forcing the water to move laterally along coal seams until it breaks out at the surface. The farmed portion of the Fort Union area cover another 100,000 square miles (4,500 in Montana), making a total of 228,000 square miles (17,000 in Montana or about 10.5 million acres) of potential saline seep in the northern Great Plains (Figure 2). These plains are the major grain-growing region for North America. The cropping sequence over the entire region--generally an alternate crop-fallow system--is the same as that on the Highwood Bench.

Over 90 percent of eastern Montana's cultivated dryland is in the Missouri River Basin. Based on discharge records at Fort Benton

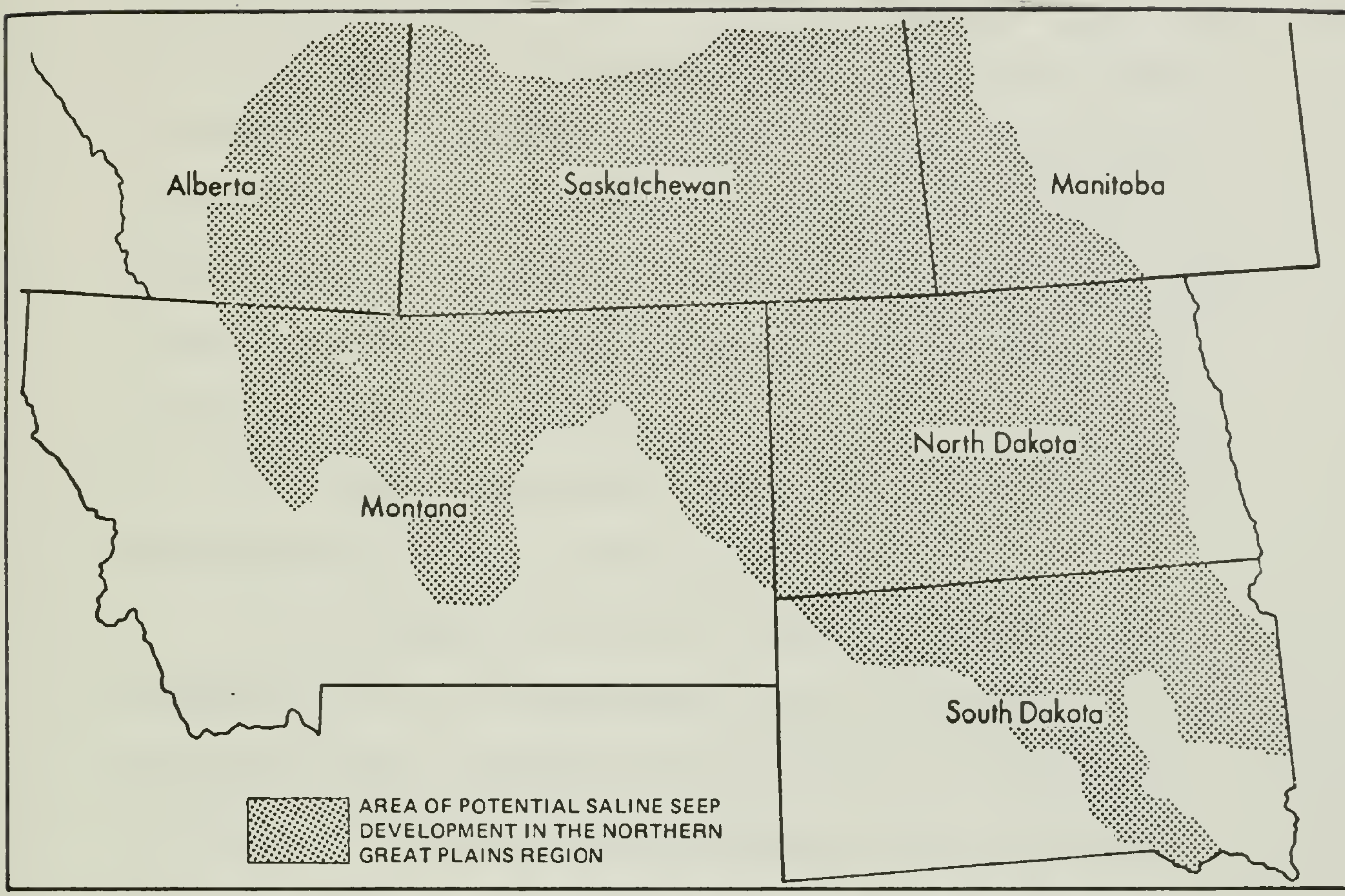


Fig. 2 Northern Great Plains Region, Showing Area of Potential Saline Seep Development.

and limited groundwater data, the water table within the glacial till is rising an average four to ten inches a year and the basin is storing considerably more water than it did prior to farming. More complete discharge data from both the Missouri and Yellowstone Rivers reveal that the Missouri River Basin is storing 4.3 million acre-feet of water a year over that being stored by the Yellowstone River Basin, a basin of much less extensive farming (22). If the annual 4-to- 10-inch water table rise is projected over all the cultivated farm area of the Missouri Basin, it accounts for most of the excess storage.

The discharge of the Missouri River, and presumable direct runoff into the river, was significantly greater from 1891 to 1915 than from 1915 to 1940. Since 1940, discharge has been gradually rising as excess water began seeping into tributary drainages. The decline from 1915 to 1940 was undoubtedly accentuated by extended drought. Even so, groundwater buildup associated with the crop-fallow system appears to be the most plausible explanation for the reduced discharge.

Saline seep development is most pronounced where the glacial till is less than 30 feet thick. Excess water appears to be accumulating over large areas where the till is much thicker, but has not yet reached the surface. Along with the extensive loss of valuable farmland, widespread deterioration of surface and shallow groundwater resources seems inevitable as long as factors contributing to this process are maintained.

ECOLOGICAL ASPECTS AND IMPLICATIONS

Saline seep is essentially an ecological problem. It involves all the major components, both biotic and abiotic, of the ecosystem known broadly as the northern Great Plains. Since 1910 the preponderant biotic influence upon that ecosystem has been man and his agricultural systems, only now to be manifest, over half a century later, in the form of saline seep.

Those who attack the problem need to know how serious the problem is by inventorying land, water, and biotic resources, and monitoring any subsequent deterioration. An understanding of complex ecological relationships responsible for maintaining balance in the remaining undisturbed portions of the ecosystem is needed in land management practices.

Environmental Effects

Although saline seep destroys an estimated 8,000 to 25,000 acres of productive Montana land each year, facts are not available to determine the precise location, extent, and progression of the problem. To gain such information the Governor's Committee on Saline Seep recently adopted a standardized form with which to inventory all agricultural producers in the affected area. Also, state and federal personnel will try to apply the space-age remote sensing of Earth

Resources Observation System (EROS) and Earth Resources Technological Satellite (ERTS) to delineate the scope of the problem (11) (19). Even with a more definitive figure of total acreage destroyed, however, the impact on production of agricultural commodities and the loss in terms of market value will still be difficult, if not impossible, to ascertain.

Saline seep is certainly responsible in part for increasing saline pollution of Montana's water (28). The growing unpalatability of community water supplies at Nashua, Wiota, and Frazer has been attributed to saline seep (23), and nitrate poisoning of livestock from salinized farm reservoirs has recently been reported in the Fort Benton and Denton areas (3). Seeps develop in areas having no alternate source of fresh water for household, livestock, or wildlife purposes (15). Siltation from erosion, probably the most important water quality problem in dryland streams, is likely to increase with loss of vegetative cover brought on by the seeps (17).

Representative analyses of water and salt samples from the Highwood Bench and Missouri River, along with recommended standards for domestic water supplies, are shown in Table 1.

In all surface water, groundwater, and salt samples collected on the Highwood Bench, the predominant dissolved constituents are sodium, magnesium, sulfate, and nitrate. The samples also contain unusually high concentrations of trace elements: aluminim, iron,

TABLE 1

Analyses of Salt and Water Samples in the Fort Benton Area.

(All values are in milligrams per liter (mg/l) except as indicated.)

			Groundwater			Surface Water		
Parameter	Salt Sample (micrograms per gram)	Test Hole HC3 (70)	Test Hole BF2 (70)	Test Hole D21 (72)	Bramlette Reservoir 1969	Bramlette Reservoir 1972	Missouri River at Fort Benton	Recommended Drinking Water Standards
Sulfate (SO_4)	536,000	26,475	33,000	36,730	3,600	5,690	55	250
Nitrate (NO_3)	12,800	2,262	881	918	115	14	0	45
Chloride (Cl)	10,200	168	255	280	57	96	8	250
Bicarbonate (HCO_3)	4,000	878	288	545	334	425	163	
Sodium (Na)	110,000	4,821	7,045	5,600	720	950	42	
Magnesium (Mg)	72,000	4,607	4,546	6,295	498	908	14	
Calcium (Ca)	8,200	341	594	446	215	273	18	
Potassium (K)		41	6	45	16	28		
Strontium (Sr)		22.5	8.1	7.7	2.0	2.4	.22	
Lithium (Li)		2.8	1.1	.99	.28	.38	.04	
Iron (Fe)	3,340	5.1	8.0	1.4	.14	.20	.13	.30
Manganese (Mn)	112	.87	.70	1.1	.24	.39	.01	.05
Aluminum (Al)	1,108	8.2	8.2	2.0	*.10	*.10	1.0	
Copper (Cu)	5.2	.12	.14	.12	.02	.03	.01	1.0
Lead (Pb)	28.0	.78	.78	1.3	.20	.13	*.02	.05
Zinc (Zn)	22.0	1.32	.69	.10	.03	.02	.03	5.0
Nickel (Ni)	9.6	.34	.52	.42	.05	.03	*.02	
Cobalt (Co)		.22	.25	.38	*.05	.10	*.02	
Cadmium (Cd)		.11	.12	.06	.01	.01	*.01	.01
Chromium (Cr)		.12	.12	.22	*.02	.02	*.02	.05
Silver (Ag)	1.48	.08	.08	.13	.02	.01	*.01	.05
pH		8.08	8.35	7.46	8.00	7.63	8.00	6.0-8.5
Specific Conductance (micromhos)		26,700	31,750	31,700	5,860	8,110	405	
Total Dissolved Solids		39,690	46,750	50,880	5,566	8,380	307	500

*means "less than."

manganese, strontium, lead, copper, zinc, nickel, chromium, cadium, lithium, and silver. Most of these elements are rarely detected in water samples from other areas. Groundwater samples commonly contain more than 25,000 milligrams per liter (mg/l) total dissolved solids (TDS) with some exceeding 50,000 mg/l TDS, which is more saline than sea water (36,000 mg/l TDS).

High nutrient levels have created eutrophic conditions in all the small ponds and reservoirs on the Highwood Bench. Almost all the wells, springs, and reservoirs on the bench, which were once fresh, are now highly saline. And many of the reservoirs that once produced trout no longer support a sport fishery. The EPA National Field Investigations Center, Cincinnati, at the request of the Governor's Saline Seep Committee and the EQC, will conduct a limnological reconnaissance of these reservoirs to determine the exact cause or causes of fish disappearances.

The demise of Highwood Bench reservoirs has been linked to the acceleration of saline seeps. Three characteristics of saline seep waters--TDS, heavy metals, and nutrients--alone or in combination, are the suspected causative agents for fish mortalities in these waters.

Levels of heavy metals in at least one reservoir on the Highwood Bench (Table 1) exceeded recommended water quality standards for fish and aquatic life (20). TDS were also above recommended levels for freshwater life, and nitrate was extremely high in the one reservoir sampled. As noted in Table 1 nitrate is one of the major components of the salt deposited by seeps on the bench and may be partly responsible for eutrophication of area reservoirs. Although increased aquatic plant growth may have depleted oxygen levels and thereby be the single cause

of mortalities, the stresses from sublethal oxygen levels may have made fish more vulnerable to the other toxic agents--heavy metals and TDS.

Several basic questions must be answered if surface water quality problems fostered by saline seep are to be dealt with: what components of seep water are causing the damage; how severe is the damage and what is the potential for spread; and how may damaged waters be restored?

The implications of seep-caused water pollution are clear. Montana is a headwater recharge area for downstream states in the Missouri River Basin, and any degradation of water quality here will affect downstream uses. Unless saline seep is checked, present water uses such as drinking, recreation, and fish and wildlife, will be seriously degraded and water treatment will become more expensive.

The effects of saline seep on wildlife habitat and populations are even more uncertain. At the fringes of most seeps, salt-tolerant weeds, mostly Kochia (Kochia scoparia or summer cypress), provide some cover (and perhaps food) that would not otherwise be available (13). The seep-affected area is within the range of upland game birds and migrant waterfowl. In some cases seeps are providing habitat for these game birds where none existed before (27).

The major concern of the wildlife biologists is that seeps may eventually destroy or greatly reduce the carrying capacity of the

land. One can only speculate on the fate of upland game birds in Montana's grain belt and of nesting and migrant waterfowl in Montana's prairie potholes should saline seeps proliferate. Wildlife population trends in response to the spreading saline problem have not been established. Perhaps what Aldo Leopold observed 25 years ago can be expected. He was reflecting upon a jackpine sand farm in Wisconsin and depleted soils and fallen civilizations in North Africa and the Middle East:

> This. . . display of disorganization in the land seems to be similar to disease in an animal, except that it never culminates in complete disorganization or death. The land recovers, but at some reduced level of complexity, and with a reduced carrying capacity for people, plants, and animals (18).

Natural and Agricultural Ecosystems

Research on saline seep in Montana has been insufficient. Efforts have been restricted to geology and subsurface hydrology, as described in the first part of this paper, and to soil moisture management by crop selection and farming practices. These studies should of course be continued and expanded.

Ultimately, however, the solution to the problem may depend on understanding complex ecological relationships as they operated, apparently with some success in forestalling saline seeps, for many thousand years on the native prairie of the Highwood Bench and similar areas of the northern plains. Thus it is important to compare that

native prairie ecosystem with agricultural systems, particularly crop-fallow, and to understand why the one has succeeded where the other has failed.

The undisturbed aboriginal prairie ecosystem covering the glacial till of northeastern Montana represents an accumulated "wisdom" of about 15,000 years. Since the retreat of the last ice age glacier, the plant community has been evolving, by trial and error selection and replacement of species, to the point of optimum environmental adaptation. The grasses, forbs, and shrubs of the native prairie, together with the fauna, geology, soils, and hydrology, and such extrinsic factors as precipitation, temperature, solar radiation, and their seasonality function in a finely tuned dynamic equilibrium that is only remotely approached in the most diversified of man's agricultural systems. The ecologic flexibility of the hundreds of native plant species allows them to form communities adapted to a wide array of environmental situations (including extreme natural fluctuations in climate, such as very dry, wet, warm, or cold periods). The destiny of a diverse native plant community is more predictable than that of a homogeneous system such as a field of grain: patchy distribution plus the inherent resistance of some native species to insects and disease make the diverse community much less susceptible than monoculture to widespread devastation.

The most important characteristics of natural systems in preventing seeps appear to be efficient water use and restricted

vertical percolation. Efficient water use implies a permanently expanded root system at all depths in the soil profile. Annual grasses and forbs, like small grain crops, obtain their water only from the upper soil levels; their root systems are shallow, expanding and functioning only during the growing season. Perennial grasses and shrubs, absent from most cropping systems, use water that escapes from shallow-rooted plants into the subsoil; their root systems are deeper, permanently expanded, and functional over a longer period.

In nature, big sagebrush (Artemisia tridentata) occupies the niche of a deep-rooted perennial shrub. A Department of Fish and Game study in the Winnett area shows that a substantial amount of moisture was released into the soil during the year sagebrush was treated with 2, 4-D (24). In this study, even perennial grasses could not grow enough during the season of treatment to consume all the released moisture.

Precipitation that reaches the ground must either run off, evaporate, or soak in. Water penetrating the ground surface is infiltration, whereas water moving through the soil is percolation.

Infiltration studies conducted on fallow and sod (native grassland) situations on the Highwood Bench show no appreciable difference in infiltration rates but greater horizontal water movement with the sod system. The reason for this greater horizontal movement in sod is the humus layer at the soil surface. This pourous mulch, usually over two inches thick, acts as a sponge, or soil moisture storage

reservoir, and is able to absorb considerable amounts of precipitation (10). Although infiltration is aided, the water is distributed horizontally, allowing it to be used by plants before it has a chance to percolate below the root zone.

The surface mulch also protects the soil from drying and consequent structural aberrations. Without this humus cover, clay soils are subject to alternate wetting and drying, which causes cracks that allow more rapid and deeper penetration of water (25). As noted earlier, vertical jointing occurs in the glacial till of the Highwood Bench. In such situations a surface mulch may be essential to prevent rapid and excessive percolation of water below the root zone and consequently to prevent the formation of saline seeps.

To apply these and other ecological relationships in land management and cropping practices will require integrated ecological research, encompassing geology and hydrology, basic grassland ecology, and plant and soil science. If the approach is limited to the traditional realm of agriculture, a practical solution may be no closer than it is today.

PROSPECTS FOR RETARDATION

Most authorities agree that saline seeps are nearly irreversible; once the productivity of land is destroyed, reclamation is difficult. With time, the salts can possibly be leached below the root zone provided the flow of saline water is cut off. However, the principal objective is prevention rather than reclamation.

As long as the crop-fallow system is practiced on the northern plains the conditions favoring seeps will continue and the problem cannot be totally prevented. In certain areas, however, seep flows can be retarded and perhaps even discontinued.

Serious methods to control saline seep have one objective in common: remove excess water from the recharge area. The discharge area, where seeps are manifest, is less important from the control standpoint. Preventive methods may be grouped into two categories: farming practices and nonfarming practices.

Farming Practices

To keep excess water from reaching below the root zone in recharge areas, any vegetation is clearly better than no vegetation at all (fallow). Stems and leaves intercept moisture and enhance evaporation. Plants function like pumps in transporting moisture from the soil up through the roots to the aerial parts, where it can be transpired. Profitable cereal, seed, or forage crops are a logical first choice for moisture control purposes.

Currently, soil moisture management through crop selection and farming methods is probably the only practical means of controlling saline seep. Reverting to a grassland/grazing economy seems out of the question in most areas, given today's grain prices and land values.

The nonfarming practices listed in the following section do not appear amenable to widespread application. Because with few exceptions saline seep is a problem only croplands, an enlightened program of soil moisture management will depend on the individual producer.

MSU researchers are examining several approaches to seep control in studies on the Highwood Bench (4); their preliminary findings are available to farmers in a recent bulletin from the MCES (5).

An initial alternative is to crop small grains every year instead of every other year, but this method of seep control does not appear to be feasible. Since winter and spring wheat use soil moisture to a depth of only four to seven feet, and root systems may not be established at snowmelt or when rains arrive, water may still move beyond the root zone in wet years. Only a few of the minor seeps have disappeared from the Highwood Bench after two dry years in combination with annual cropping (5). Also, harvest during the second or subsequent years may be too meager to pay farming costs, except in areas receiving adequate annual precipitation.

Deep snow accumulation may be responsible for particular saline seeps, but a certain amount of snow accumulation is needed for successful annual cropping. Standing stubble and intermittent rows of perennial grasses, which can hold snow in place and reduce drifts, are being studied by MSU and ARS as means of controlling the amount of water entering the soil in recharge areas.

Dryland alfalfa and intermediate and tall wheatgrasses are better prospects than small grains for drying out soil and subsoil on recharge areas (5). Sweetclover, sainfoin, vetch, corn, millet, and safflower were also tested by the MSU team, but these plants used less soil moisture than wheatgrass or alfalfa. Although effective, widespread conversion to these crops will raise serious economic, ecologic, and practical questions. For example, can farmers adapt mechanization to changing crops and still be able to operate at a profit? Can a market for forage or seed crops be established and maintained in a region now largely devoted to cereal crops? What will be the long-term environmental consequences of such crop conversions?

According to the MSU studies, Kochia is effective at reducing soil water; it grows primarily in saline soils on discharge areas; and it may produce over five tons of forage an acre (4). Kochia also makes excellent hay; "cattle eat it just like alfalfa (1)" Besides being palatable, it is nutritious (12).

Although deep-rooted and a vigorous water user, Kochia left standing over winter will trap snow, which will contribute to the seep the following spring. No evidence shows, however, that such moisture accumulation in the form of snow will exceed or even approach the amount used by the plant during the growing season. Furthermore, snow accumulation on discharge areas (where Kochia grows) is not as critical in perpetuating seeps as accumulation on recharge areas. Kochia is

apparently well adapted to growing in seeps where agricultural plants have failed, and any proposals for control of this plant and replacement by others should be seriously examined. Fertilizer applications are known to enhance plant growth in some situations and thereby aid in soil water reduction. Only as much fertilizer as the plants can use should be applied; otherwise excess nutrients might contaminate surface and ground waters.

Farmers need to recognize that successful cropping in seep areas must include soil moisture and water table management. A simple soil auger should become standard equipment to help farmers decide whether to plant and what to plant depending on soil moisture content and depth to groundwater. Farmers will need to consider the penetration and character of root systems as well as above-ground plant production; they may need to diversity--to call on any one of a number of crops depending on moisture use and needs. Water tables should not be allowed to rise any further, yet adequate soil moisture in the root zone is a prerequisite to profitable cropping. Some way, a moisture balance must be maintained, neither too little nor too much can be tolerated.

For convenience and economy, farming has traditionally been practiced on geometric land patterns, usually rectangles or squares. Within the last half-century the average size of these units has greatly

increased, mainly because of large, mechanized farm implements. However, the diverse characteristics of soil, subsoil, substrata, and surface and subsurface hydrology do not conform to these regular patterns. On larger fields especially, these land features,. many of which determine the potential for seep development, are not consistent. Applications for controlling seep may be necessary and effective in one part of a field, yet unnecessary and ineffective or even counter-productive in another. For example, a field might cover both a recharge area and a discharge area with varying soil moisture content and water table levels throughout; a deep-rooted perennial would be effective where the water table is deep and surface moisture deficient, but annual cropping to small grains may be more productive and equally as effective where surface moisture is adequate.

In short, farmers may not be able to continue imposing conventional field geometry and still hope to solve the problem of saline seep. They may need instead to adapt more closely to the varied capabilities and constraints of the land, which in some areas may mean smaller fields, fields of irregular shape, both of these, or possibly no farming at all. They may also be unable to continue present monocultural cropping practices. Farmers, in certain situations, should be willing and able to crop not only cereal grains but also grasses, legumes, or whatever else may be suitable.

Nonfarming Practices

Nonfarming methods control both the flow of fresh water into the recharge area and the flow of saline water from the discharge area. They include underground drainage, ponding, land grading, and phreatophytes. (A phreatophyte is a plant capable of drawing its supply of moisture from the groundwater reservoir or from the capillary fringe above it.)

Land grading is probably the most feasible and effective alternative. This involves contouring the land surface in recharge areas to enhance runoff and eliminate short-term ponding on fallow fields, thereby reducing the water contributing to seeps. Runoff could be directed along grassed drainageways to reduce erosion potential.

The conventional method of lowering water tables is artificial drainage. But the impermeability and thickness of the till (it averages about 25 feet), and the problem of what to do with the saline water, make artificial drainage of the discharge areas infeasible. Most affected areas would require a very extensive and expensive network of tiles (16).

In any event, the question remains--what is to become of the excess saline water now flowing freely from the ground? Contamination of fresh surface waters is clearly a problem, and any purposeful discharge through drainage and/or diversion of saline waters would

certainly conflict with state and federal nondegradation policies.

One method of saline water control is to collect saline discharges in sealed ponds and to allow the water to evaporate, leaving the salts behind. This method would disturb a considerable amount of land and would probably not be economically feasible (16).

Another method of managing seep water in discharge areas is to establish stands of salt-tolerant phreatophytes. One candidate is five-stamen tamarisk (Tamarix pentandra), a decidious tree native to Eurasia whose root system sometimes extends 90 feet or more down to the water table. This species has spread with explosive speed through the drainage systems of the Southwest. Other nonspreading Tamarix species may be more desirable.

Nevertheless, native plants should be considered before contemplating introductions. More likely candidates from area flora include saltgrass (Distichlis stricta), picklewood (Salicornia rubra), and species of Suaeda or seep weed. Kochia and foxtail barley (Hordeumjubatum) naturally take over seep areas but occupy only the dry fringes.

These and other steps may be necessary to prevent the progressive depletion of the soil resource base of northeastern Montana and other glaciated lands of the northern Great Plains. In the words of State Senator George Darrow, saline seep is

> . . . not an isolated local problem, it is a systemic problem . . . The overall dimensions of the saline seep problem involve nothing less than the future of Montana's agricultural economy. We now understand that that future is in jeopardy. Our response will determine that future (9).

TENTATIVE RESEARCH CONCLUSIONS

1. Although water contributing to saline seeps is locally derived, the problem is regional and systemic, potentially encompassing a major portion of the northern Great Plains in both the United States and Canada.

2. Natural grassland systems are more effective than agricultural systems in forestalling saline seep development.

3. Saline seeps are clearly caused by the present crop-fallow system of farming superimposed on the hydrologic and geologic conditions of the northern Great Plains.

4. Soil and water pollution are the two most severe environmental impacts of saline seep; little is known about its impact on wildlife populations.

5. The true extent of losses from saline seep, in terms of productive land surface and market value of agricultural commodities is unknown.

6. Reclamation proposals are only stopgap solutions; the only real hope lies with individual producers and an enlightened program of soil moisture management based on sound ecological principles.

7. The majority of the excess water moving downward through the glacial till and accumulating on the impermeable shale comes during the spring months of the year--March, April, May, and June.

8. On fallow areas, a water-table rise of one to five feet can be expected during years with average or above average spring precipitation. These water table highs gradually decline during the rest of the year, but normally do not reach the previous year's low indicating a continual build-up of excess water over the years. As a result, each succeeding wet cycle makes the saline-seep problem worse.

9. The size of each wet-saline area (discharge area) is related directly to the size of the adjacent upland recharge area. Every effort should be made to delineate the major recharge areas to make sure that the cropping system is intensified in these areas. Frequently, all the attention is given to the seep (discharge) area and the upland (recharge) area is left fallow.

10. In many areas the "perched" water table has built up to a point where coulees which were formerly dry most of the year are now starting to flow year-round. At the present time most of the saline water is evaporated before reaching the perennial streams leaving the salts behind to be flushed away during spring runoff. Unless the growth and development of saline seeps are stopped soon many coulees will start to flow appreciable quantities of highly saline water to all perennial

streams throughout the region with the majority of the water coming during the low-flow season when it could rapidly impair the quality of the entire stream. Because Montana is a headwater state for the Missouri and Yellowstone River Basins, the potential widespread deterioration of water quality is of national interest and concern.

11. In all water and salt samples collected on the Highwood Bench area, the predominant dissolved constituents were sodium (Na), magnesium (Mg), sulfate (SO_4), and nitrate (NO_3). The samples analyzed so far also contain unusually high concentrations of trace metals, namely aluminum, iron, manganese, strontium, lead, copper, zinc, nickel, chromium, molybdenum, selenium, and vanadium. The majority of these metals are rarely ever detected in water samples. Groundwater samples commonly contain more than 25,000 milligrams per liter (mg/l) total dissolved solids. High nutrient levels (nitrates and phosphates) have created eutrophic conditions in all the small ponds and reservoirs in the area. Practically all the springs and reservoirs on the Highwood Bench which were once fresh water are now highly saline. This relatively rapid deterioration of all potable water supplies in this area should serve as a warning to what may happen to the water-resources of the entire region if the saline-seep problem is ignored.

12. All available hydrogeological data indicate that the formation and development of saline seeps are a result of local, <u>not</u> regional, flow systems.

13. Infiltration studies on high, poorly drained, recharge areas indicate that over five inches of water per day can move downward through the glacial till. These high infiltration rates greatly exceed previous estimates.

14. Saline-seep development is not just limited to high precipitation areas. During the past two years large outbreaks of saline seeps have been observed in areas where average annual precipitation is less than 12 inches (Loma, Power-Dutton, and Columbus-Rapelje areas).

15. At the present time saline-seep development is particularly pronounced in areas where the glacial till is relatively thin (zero to 30 feet thick). Excess water is undoubtedly accumulating over large areas where the glacial till is much thicker, but as yet has not expressed itself at the surface.

16. According to a survey conducted by the United States Soil Conservation Service in 1971, more than 80,000 acres of non-irrigaged cropland in Montana had been lost to saline seeps. Serious outbreaks of saline seeps have now appeared in most of northcentral and northeastern Montana. At the present time, it is estimated that an additional area of 100,000 to 150,000 acres of cropland has been lost, but no recent survey has been conducted to prove or disprove this estimate. Possibly such a survey should be conducted soon. Also, if the acreage of saline farm, recreation, and stock ponds, as well as badly eroded

coulees and "seeped" drainageways were included, the affected area would be much greater.

17. Geological conditions, that is, a variable thickness of glacial till underlain by thick sequences of black marine shale (Colorado and Bearpaw Formations), are similar over vast areas of Montana (12,500 square miles), North Dakota and South Dakota (45,500 square miles) and the three prairie provinces of Canada (70,000 square miles). In addition to the above-mentioned region, saline seeps are also spreading in areas underlain by siltstone, sandstone, shale, and coal (Fort Union Formation). Here again excess water is moving downward and accumulating on thin impermeable shale beds forcing the water to move laterally along coal seams until it breaks out at the surface. This area covers an additional 100,000 square miles making a total of 228,000 square miles of potential saline-seep development in the northern Great Plains region of the United States and Canada. This is the major grain-growing region for both countries. The cropping sequence over this entire region--generally an alternate crop-fallow system--is the same one being used on the Highwood Bench, northcentral Montana.

RECOMMENDATIONS

1. Initiate an extensive, coordinated research program dealing with all aspects of the saline seep problem. Critical research needs include accurate information on:

A. Total acreage affected.

B. Annual loss of crops and livestock in terms of market value.

C. Extent of seep-caused water quality problems and cost of restoring affected waters to beneficial use.

D. And, impacts on fish and wildlife resources and losses to the associate recreation industry.

2. Identify major recharge areas and where feasible improve the runoff efficiency on fallow fields to avoid ponding.

3. Intensify cropping practices over the entire northern plains region, particularly in recharge areas and during years with average or above average spring precipitation.

4. Rotate perennial grasses and deep-rooted legumes into the cropping program. Available data show that alfalfa can use soil moisture to a depth of 25 feet once it gets established.

5. Determine why the native plant cover, working together with the hydrologic and soils regime, has been able to prevent saline seeps, and apply this knowledge in farming practice.

FUTURE PLANS

The widespread occurrence and rapid growth of saline seeps have now been recognized as one of the most serious conservation problems in the Northern Great Plains. The funds received from the Office of Water Research and Technology for this project were instrumental in providing "seed" money to initiate an active research program to study this problem.

Throughout the project there has been very close cooperation between the Montana Bureau of Mines and Geology, Montana State University, Montana Agricultural Experiment Station, Montana Extension Service, Montana Environmental Quality Council, United States Agricultural Research Service, United States Soil Conservation Service, United States Geological Survey, United States Environmental Protection Agency, and local farming organizations. The principal investigator has been responsible for the hydrogeological aspects of the problem. The results and information gathered during the project have been used by all the other organizations.

A new project partially supported by the Office of Water Research and Technology funds has been initiated to examine the regional development of saline seeps. This will be a cooperative venture with the aforementioned organizations and much of the data gathered for this study will be used in these future studies.

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